TITLE OF THE INVENTION

HEARING AID HAVING ACOUSTICAL FEEDBACK PROTECTION

CROSS REFERENCE TO RELATED APPLICATIONS

This application is related to U.S. patent application serial number 10/068,487 filed on February 6, 2002 entitled HEARING AID OPERATIVE TO CANCEL SOUNDS PROPAGATING THROUGH THE HEARING AID CASE.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

N/A

BACKGROUND OF THE INVENTION

The purpose of this invention is to discriminate between audio signals propagated through the air and noise signals which are propagated through the plastic shell of the hearing aid. Most of the noise transmitted through the plastic case of the hearing aid is created within the body itself; i.e. chewing, talking, walking, etc.

The present invention utilizes two microphones, both coupled to the hearing aid case, wherein one microphone is exposed to sounds propagating through the air and the second microphone is purposely sealed from sounds propagating through the air.

In a typical hearing aid, one or more microphones convert sound transmitted through the air to an electrical signal. A signal processing system (amplifiers, filters, digital filtering, etc.) processes

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the signal, and a loudspeaker converts the processed electrical signal back to an audio signal. The hearing aid apparatus is enclosed in a plastic case that is placed In The Ear (ITE) canal or Behind The Ear (BTH).

The microphone(s) is(are) attached to the plastic case and the case is acoustically coupled to the bone and flesh of the wearer. Therefore, any sounds that originate in the skull are conducted to the microphone(s) and amplified and echoed back to the ear.

There have been many inventions for hearing aids wherein two or more microphones are used to cancel ambient noise. Both microphones "hear" the same audio signal that is propagating through the air. The noise cancellation technique assumes that the noise source is much further distant from the two microphones as compared to the local or desired audio signal. As long as the noise is generated at a distance which is large compared to the distance between the two microphones, the signals received at each microphone will be almost equal in amplitude and phase. Then a "difference device", for example, a differential amplifier, can subtract the two microphone signals and effectively cancel the ambient noise. In addition, two or more microphones have been used with a differential amplifier to develop a directional microphone for use on a hearing aid. However, in all cases, all of the microphones were exposed to the audio signals propagating through the air in order to produce the desired effect.

In US Pat. No. 5,526,819, two microphones are used to attempt to cancel out high amplitude "body noises" (such as a cough) from the very low level desired (DPE) audio information. However, in this patent, both

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microphones are exposed to the same audio signals in the air. One of the microphones is designed to not respond to the DPE signals that are of a fixed and known frequency in this test. It is also "necessary" that the microphones be different. In addition, the patent does not give any information as to how the "second" microphone, which is less "sensitive" than the first microphone, cancels out high level noise signals but does not cancel out the low level DPE signal. There is some "hint" of how the second "less sensitive" microphone works, since the patent states, "The output of 30B is of less sensitivity so that the frequency components of the DPE signal are missing from the signal applied to the minus input of the differential amplifier." In other words, the less sensitive microphone is designed to be "less sensitive" at the specific frequency that is being looked for in this patent; i.e. frequencies F1 and F2 are applied to the ear and the instrument looks for an "echo" at 2F1-F2. Also, the ratio of F2 to F1 is fixed. This patent clearly states that the typical test procedure varies F1 from 1,000 Hertz to 8,000 Hertz in steps of 100 Hertz. Therefore, the electronics must vary the frequency response of the second microphone for each step in the input frequencies.

In claim 1, lines 21 to 29, the patent states: "Said eartip including a second microphone means with a second output lead connected thereto for generating a second electrical signal on said second output lead which is proportional to said other body noises but is not substantially proportional to distortion product emission tone generated in the ear of said human being at the frequency of 2F1-F2." This claim clearly states that the

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second microphone must be very frequency selective since it is specifically not substantially sensitive to a specific frequency. Again, since the patent requires that the frequencies F1 and F2 be varied over a wide range (typically 1 kHz to 8 kHz in 100 Hertz steps), this means that the frequency selectivity of the second microphone must also be varied accordingly.

In US Pat. No. 6,068,589, two or more microphones are used, all exposed to free air, but placed in different positions on the body (skull) so that noise generated from a relatively large distance is coupled almost equally to both microphones and canceled out, wherein noise generated nearby is selectively coupled much greater to the closer of the two microphones and less selectively to further microphone. Therefore, the "nearby" audio signal is amplified much more than those audio signals generated at a much greater distance. This improves the signal to noise ratio since the local signal is considered the "desirable signal" as compared to the noise generated at a distance. In addition, by locating the microphones on opposite sides of the skull, it is possible to increase the "directivity" of the hearing aide. Again, all of these microphones must be exposed to all of the audio signals transmitted through the air and there is no mention of using multiple microphones to cancel noise directly coupled to the hearing aid case and generated within the body.

US Pat. No. 4,622,440 also indicates the use of two microphones that are physically separated and exposed to the air in order to "hear" the audio signals transmitted through the air. As in the previous patents, this patent subtracts the audio signals generated in each microphone

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in order to cancel noise generated at a "distance" that is large compared to the physical space between the two microphones. If this "distance" is relatively large compared to the physical separation of the two microphones, than the signals received by the two microphones will be substantially equal in amplitude and phase and may be canceled using a differential amplifier.

Audio signals generated much closer to the two microphones will be coupled greater to one microphone than the other and will not be completely canceled. In this type of circuit, both microphones are exposed to air in order to cancel noise generated at a distance. This type of circuit can also be used to enhance the "directivity" of a microphone.

US Pat. No. 5,757,933 is almost identical to Pat. No. 4,622,440 except that this patent includes the use of a switch to either add the signals of the two microphones together or to subtract the signals from the two microphones. By varying the phase and gain of one microphone versus the other, the microphones can be made somewhat "directional". Both microphones must be exposed to the air.

US Pat. No. 5,402,496 again discusses the use of two microphones, both exposed to hear the audio signals transmitted through the air. The output of one microphone passes through a "first filter". To quote: "The first filter generates a reference signal by selectively passing an audio spectrum of the input signal which primarily contains the undesired component." This statement alone says that one must first "know" what the "undesired component" (i.e. noise) is, which is not useful in situations in which it is not possible to

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"know" in advance what the noise is. In addition, in this patent, both microphones are not identical.

Also, according to this invention, only one microphone is actually required. The output from this microphone is passed through a "first" filter as well as directly to the remainder of the signal processing electronics. There appears to be no explicit mention of a "second" microphone in the claims.

EP 0 782 371 B1 refers to the design of a microphone for use in hearing aids, particularly for use in "in-the-ear" (ITE) hearing aids. This patent clearly defines a technique for "mechanically" mounting a microphone in a hearing aid so that the sudden motion of the body does not pass from the body to the hearing aid shell and then to the hearing aid microphone. If this sudden motion is coupled to the microphone, the audio signal is amplified by the hearing aid electronics and passed into the ear.

The patent describes in great detail the mechanical mounting of such a microphone. This patent does not discuss nor hint of the application of a second microphone and electronics to cancel mechanical vibrations received by both microphones.

WO 97/44987 describes a hearing aid system wherein one microphone is connected to an amplifier, battery and loudspeaker (microactuator) and placed in a hermetically sealed case. The patent document also suggests the use of an acoustic array of individual microphones arranged in a horizontal row across the electronics module. This array of microphones is connected to electronics that creates a "directional" microphone which may enhance the sounds of interest while concurrently reducing noise.

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In this patent there is no attempt to reduce noise which is directly coupled to the electronic "module" from being amplified and fed back to the ear. There is no mention of using one microphone that is sealed from audio signals propagated through the air and another microphone that is purposely exposed to audio signals propagated through the air.

EP 0 364 037 B1 teaches the use of two microphones, both exposed to audio signals propagated through the air, wherein one microphone is specifically designed to be sensitive to audio signals that originate close to it and the second microphone to be sensitive to audio signals which originate at a relatively large distance from the microphone. The outputs of the two microphones are electronically subtracted from each other in order to suppress hearing aid oscillation caused by audio feedback from the loudspeaker to the microphone.

In this patent the two microphones "must" be of different design in order for one microphone to be only sensitive to sound "close to it". The patent does not discuss the problem of audio signals coupled directly to the microphones via the hearing aid case. In addition, both the microphones in this patent must be exposed to the air.

WO 94/25959 describes a microphone and electronic module wherein the microphone is placed in the ear and sensitive only to sounds passing from the inside of the ear to the outside of the ear (the opposite direction from the normal hearing aid). These "outbound" audio signals are amplified and electrically transmitted to a remote receiver. Noise reduction and cancellation features are described in this invention. This patent

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document requires that the inner ear be sealed from the air external to the ear and that one microphone be placed into this sealed chamber in order to be subjected to audio signals originating from the inner ear. A second microphone is placed external to the ear to be sensitive to noise originating outside of the ear. The signals from these two microphones are electronically processed to subtract the noise external to the ear from the same type of noise generated from inside the ear.

This patent clearly describes the use of a "structural configuration of the earpiece and gasket around extension section 147 (that) substantially eliminates audio vibrations conducted by the bone and tissue of the earpiece wearer." "Such sound gasketing avoids audio vibration pickup of sound transmitted by the canal wall. Furthermore, the gasket composition dampens any audio vibration pickup of sound through the gasket material touching the canal inner wall."

EP 0 354 698 B1 specifically concerns hearing aids and their assembly and is especially concerned with the long-felt need to avoid the amplification of noise caused by vibrations of either the casing or the components of the hearing aid. This patent attempts to solve this problem by making the hearing aid case out of a new plastic type material described as "a viscoelastic layer adhering the transducer to the casing". This solution is totally mechanical and the patent specifically states that "… some hearing aids include electronic devices to filter out noise. Not only are electronic devices quite expensive, but they also can take up valuable space." Thus, this patent attempts to solve the problem of

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vibrations coupled to the hearing aid case by mechanical means.

WO 96/29009 describes a configuration of two microphones and electronics wherein one microphone is positioned to sense body sounds of a patient when the transducer (microphone) is placed against the patient's skin and the second microphone is positioned to sense noise in the external environment close to the first microphone. In this document, the two microphones are purposely "acoustically and mechanically isolated from each other". This is the classical case wherein two microphones are used to subtract one source of noise from another. However, in this case the external noise is normally very much larger than the "internal noise" generated by the body. Therefore, there must be very specific electronic signal processing to subtract the very large external noise from the very small internal noise and not end up with a very large (negative phase) external noise.

Since the level of the external noise is not known relative to the internal noise, this document requires the use of a "digital signal processor" coupled to the first and second microphones to process the audio signals to produce an output signal that is indicative of the very small body sounds as compared to the very large external noise. How the "digital signal processor" actually determines how to subtract the very large external noise from the very small internal noise is not described.

WO 98/43567 describes a hearing aid noise cancellation system wherein the hearing aid specifically does not completely "plug the ear"; that is, the hearing

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aid has a "vent" so that sound can propagate directly to the inner ear without passing through the electronics of the hearing aid. In this type of hearing aid, the ear hears the sum of sounds received directly through the "vent" and also via the electronic microphone and loudspeaker of the hearing aid. In this document there is only one microphone. This microphone and the loudspeaker are both acoustically coupled to the inner ear via a hollow tube. Any sound that reaches the inner ear via the vent is (1) directly heard by the inner ear and (2) picked up by the microphone, processed, and fed back to the loudspeaker to cancel unwanted "noise" signals. The process of active noise cancellation is well known (see US Patent 4,473,906). As discussed in the WO 96/29009 patent document above, the WO 98/43567 patent document must "predetermine" what the noise is in order to cancel out this noise. This is the basic problem of all hearing aids designed to improve the intelligibility of speech signals. This patent does show any specific method of signal processing to improve the intelligibility of speech signals.

WO 98/19498 relates to the design of an ear muffler to reduce ambient noise from entering the ear and protect the ear against damage. This patent does not use any microphones or electronics.

WO 93/23942 describes the development of an "ear-mounted microphone" and speaker that does not require entry of any physical structure within the ear canal. In this patent document, "Acoustical isolation means is coupled between the speaker element and the housing for selectively isolating undesirable frequencies that might interfere with sensitivity of audio pick up at the

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microphone…" This patent document does not use two microphones to acoustically isolate the speaker from the housing using electrical means. It clearly uses mechanical means to isolate the speaker from the housing. Also, in this document, the speaker directs its sound "outside" of the ear and not into the ear. In the exact reverse from hearing aids, this invention places the microphone inside the ear and the speaker on the outside of the ear. The document also claims to have noise reduction from the case to the microphone because the sound coupled from the housing to the vibration rings and then to the microphone somehow have equal and opposite phase relationships when they arrive at the microphone. There is, however, no explanation of this conclusion. The document also states: "… it is necessary to acoustically isolate the speaker element 13 from the casing. In the present invention, this is accomplished by tuning the insulation means 50 similar to operation of a band pass filter within radio circuitry. Specifically, the speaker element 13 is mounted to the end housing 36 through a nonvibrational ring 50 which extends around the speaker element and operates to isolate the housing as sound insulation means from the speaker element." The "nonvibrational ring," however, is not described or explained.

A hearing aid made by Oticon employs a hollow tube which extends from a loudspeaker on a hearing aid case into the ear canal to direct sound into a deeper portion of the ear. The tube is supported by a spoked disk to provide open spaces to eliminate the occlusion effect. Audio oscillations caused by acoustical feedback are minimized by reducing the audio gain of the hearing aid

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amplifier at selected frequencies or bands of frequencies; however, the reduction in audio gain to prevent oscillations also reduces the maximum available gain to compensate for high frequency hearing loss. This type of hearing aid is therefore unsuitable for many persons.

SUMMARY OF THE INVENTION

The present invention relates to a hearing aid that addresses the problem of sounds created internally. In the present hearing aid, at least two microphones are used, one attached to the plastic case of the hearing aid and isolated from free air, and a second microphone, also attached to the plastic case, but exposed to free air. Only the second microphone, open to the air, converts audio information conducted through free air from an external audio source to electrical signals. Both microphones convert audio signals that are conducted via the plastic case to electrical signals. The two microphones are connected to a difference device such as a differential amplifier that causes cancellation of the signals that are conducted through the plastic case. Because the path length of the audio signals via the plastic case is very short, the amplitude and phase of the audio signals received by both microphones is nearly equal. Therefore, high cancellation of any audio signals present in the plastic case can be achieved. The gain and phase of one microphone versus the second microphone could be adjusted to enhance cancellation.

In another aspect of the invention, a hearing aid of the behind-the-ear (BTE) type couples sound from the hearing aid loudspeaker through a hollow tube to an inner

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portion of the ear. A second hollow tube is coupled between a third microphone on the hearing aid case and an outer portion of the ear. Some sound emanating from the tube disposed in the inner ear, exits the ear and is picked up by the second tube and directed to the third microphone. The signal from the third microphone is nulled out by the electronic circuitry of the hearing aid. The gain and phase of the signals picked up by the second tube are automatically adjusted to provide the intended nulling and resulting minimization of acoustical feedback. Gain and phase of the signal from the third microphone to the electronic circuitry are initially set by use of test frequencies which are stored for later use in the hearing aid.

DESCRIPTION OF THE DRAWINGS

The invention will be more fully understood from the following detailed description taken in conjunction with the accompanying drawings in which:

Fig. 1 is a schematic view of an audio signal generated at a physical location centered between two microphones;

Fig. 2 is a schematic view of an audio signal generated at a physical location farthest from one microphone relative to the other microphone;

Fig. 3 is a schematic diagram for determining a desired audio output level for a one-microphone hearing aid;

Fig. 4 is a schematic diagram of the audio output level for a two-microphone hearing aid in which both microphones receive external audio signals through free air;

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Fig. 5 is a schematic diagram of the audio output level for a two-microphone hearing aid of the present invention in which one microphone is sealed from external audio signals through free air;

Fig. 6 is an exploded view of a hearing aid according to the present invention;

Fig. 7 is an exploded view of a further embodiment of a hearing aid according to the present invention;

Fig. 8 is a schematic diagram of a further embodiment of the circuitry of the present invention; and

Fig. 9 is a schematic diagram of a further embodiment of the present invention in which two microphones receive audio signals through free air and a third microphone is sealed from external audio signals through fee air;

Fig. 10 is a schematic diagram of a further embodiment of the invention in which the hearing aid is of the behind the ear type and having a pair of hollow tubes for coupling sound into the ear and for nulling out acoustical feedback signals; and

Fig. 11 is a plan view of a support disk employed in the embodiment of Fig. 10.

DETAILED DESCRIPTION OF THE INVENTION

To aid in understanding the present invention, the case of two external microphones is distinguished from the present invention in which an internal and an external microphone are used. When two external microphones are used in a "subtractive" mode through the use of, for example, a differential amplifier, the "net" audio output from these microphones is radically reduced compared to that of a single microphone. This reduction

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is due to the necessarily close spacing of the two microphones in a miniature device such as a hearing aid. For example, the spacing between two microphones may be 0.5 inches.

When an audio signal is generated at a distance of 3 feet from the ear, the amplitude of the signal received at the two microphones so closely spaced is virtually identical. Under ideal conditions, if the audio signal is generated at a physical location centered between the two microphones, there is a total cancellation of the audio signal via a differential amplifier. Referring to Fig. 1, two microphones 320, 330 are placed a distance d_1 apart and an audio source 360 is located at a distance d_2 from each of two microphones and equidistant between each microphone. In this instance, the distances d_3 and d_4 are equal. Thus, the amplitude and phase of the audio signal are identical at each microphone. When the microphone signals are subtracted from each other via a differential amplifier, the net audio signal is zero.

The conversion gain from the audio level to the electrical level for a one-microphone system can be defined as equal to 1. Thus, for a two-microphone system used in the differential mode, the conversion gain from the audio level to the electrical level is not fixed, but is determined by the angle of the audio signal relative to the two microphones, the distance of the audio signal from the two microphones, and the distance between the two microphones. Fig. 2 illustrates the location of greatest audio to electrical conversion for the two-microphone system, wherein the signals from the two microphones are subtracted from each other using a differential amplifier. The typical conversion gain from

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audio to electrical for a two-microphone system is significantly less than for a simple one-microphone system. The typical gain of a one-microphone system compared to a two-microphone system can be calculated as follows:

A simplified audio level can be given by:

$V_x = K/d$,

where

V_x = voltage out of microphone X;

K = microphone sensitivity constant whereby the voltage output of a microphone is proportional to the audio level input; and

d = distance between microphone to audio source.

This equation is relatively accurate when the distance d_2 is much greater than d_1. Thus, for the case in which the two microphones are 0.5 inch apart and the audio source is 36 inches from microphone 330:

$V_1 = K/36$ and

$V_2 = K/36.5$.

Thus

$$\begin{aligned} V_1 - V_2 &= (K/36) - (K/36.5) \\ &= 0.5K/(36 \times 36.5), \end{aligned}$$

and

$$\begin{aligned} V_1/(V_1-V_2) &= (K/36)/(0.5K/(36 \times 36.5)) \\ &= 36.5/0.5 \\ &= 73. \end{aligned}$$

Accordingly, the conversion gain from a one-microphone system is approximately 73 times greater than the conversion gain from a two-microphone differential system. This conclusion means that the audio amplifier gain for a two-microphone system must be at least 73

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times greater than that required for the one-microphone system to obtain the same audio level input to the ear.

The desired audio output level for a hearing aid can be determined from a one-microphone system, illustrated in Fig. 3. The single microphone 420 has a conversion gain of K (audio input to electrical output) followed by an audio amplifier 425 with a gain of 100. The signal from the amplifier drives a loudspeaker 440 located within the hearing aid. The relative audio output level is 100K x E, where E represents an external audio signal from a source 460. This output level sets the audio level required for normal hearing.

Fig. 4 illustrates a system with two microphones 520, 530 using a differential amplifier 523 with a gain of one and a common mode rejection ratio of 100. Thus, the differential amplifier passes one percent (0.01) of the audio signal if both audio inputs are equal and has a gain of one (1) for audio signals from only one microphone. (A differential amplifier with a rejection ratio of 100 (40dB rejection) is about the best that can be done using matching resistors with a tolerance of 1%.) In Fig. 4, E represents an external audio signal from a source 560 and N represents a noise signal generated within the wearer's body and coupled to both microphones attached to the case of the hearing aid.

Using identical microphones 520, 530 and assuming that the audio source is located 36 inches from the microphones, the conversion gain of the two-microphone system is at least 73 times less than the one-microphone system. Thus, to arrive at a final audio level of 100K x E, a further amplifier 527 with a gain of 73 is added in

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series with the first amplifier 523 and the amplifier 525 with a gain of 100.

Referring to Fig. 5, in the present invention, a first microphone 620 is used in accordance with the above discussion. A second microphone 630 is attached to the case of the hearing aid and sealed from the air, illustrated schematically in Fig. 5 by placing the microphone in a box 634. Because the audio signal E from a source 660 is heard only by the first microphone 620, this microphone has a conversion gain of K. Because the second microphone 630 is sealed from the air, it has a conversion gain of 0 for sounds that are transmitted through the air, but a conversion gain of K for sounds transmitted through the case of the hearing aid. Thus, for sounds transmitted through the air, the conversion gain of the first microphone through the differential amplifier 623 is also K. Therefore, the audio amplifier 625 has a gain of 100 to be equal to the one-microphone case.

When noise is generated within the wearer's body, it is coupled directly to the case of the hearing aid. If the second microphone 630 were not sealed, as illustrated in Fig. 4, the noise source N would be coupled to both microphones equally and would be passed through the differential amplifier with a common mode rejection of 100 (gain of 0.01). Therefore, the noise output of the differential amplifier would be 0.01N. This is multiplied by 73 and by 100 to result in a noise output of 73N.

When the second microphone is sealed, as in the present invention, the noise N is also coupled to both microphones equally and passed through the differential amplifier. Therefore, the output of the differential

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amplifier is again equal to 0.01N. This output is amplified by a gain of 100 for a net output noise of 1N. Therefore, for noise coupled directly to the shell of the hearing aid, that is, noise generated within the body, the noise generated in the ear is 73 times less when the second microphone is sealed from the air.

A hearing aid 10 according to the present invention is illustrated schematically in Fig. 6. The hearing aid shown is an in-the-ear (ITE) type hearing aid and includes a case 12 having a shell 14 and a faceplate 16 attached to a distal end 18 of the shell 14. The shell and faceplate may be formed, for example, of molded plastic. The faceplate is attached to the shell in any suitable manner, as known in the art.

A first external microphone 20 is in electrical communication with an electronics package 22 by, for example, a twisted pair of wires 24. The external microphone is attached to an outer or distally facing side 26 of the faceplate 16 of the case. The external microphone 20 is able to pick up sounds propagating through free air, that is, sounds propagating through air external to the ear, as well as sounds propagating through the case 12.

A second internal microphone 30 is also in electrical communication with the electronics package 22 by, for example, a twisted pair of wires 32. The internal microphone is enclosed in a further enclosure 34 that seals the internal microphone from sounds propagating through free air. Thus, the internal microphone is only able to pick up sounds propagating through the hearing aid shell 14 and the enclosure 34. The internal and external microphones are preferably identical such that

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the responses of both microphones to audio inputs have substantially the same audio to electrical conversion characteristics. The electronics package 22 contains subtractive circuitry for eliminating noises propagated through the hearing aid case, as discussed above in conjunction with Figs. 1-5.

The hearing aid also includes a loudspeaker 40, connected to the electronics package 22 via a twisted pair of wires 42, placed at a proximal end 44 of the shell 14 to direct audio output into the ear of the hearing aid wearer. A battery 46, covered by a protective covering 48, is provided to supply power for the hearing aid. The battery is also connected to the electronics package by, for example, a twisted pair of wires 50.

In an alternative embodiment, illustrated in Fig. 7, all of the working components of the hearing aid except a loudspeaker 144 are mechanically connected to a faceplate 116 of a case 112. An external microphone 120 is connected directly to an electronics package 122 via contacts that pass through the faceplate 116 to a distally facing side of the package. A battery 146, covered by a protective cover 148, is similarly directly connected to the electronics package 122 via contacts that pass through the faceplate to the distally facing side of the package. A second internal microphone 130 is attached to a proximally facing side of the electronics package 122 and is enclosed in an enclosure 134 sealed from the air both inside and outside of the case. In this manner, these working components can be assembled and fitted into any shell 114. In addition, the external and internal microphones are mechanically connected together and are as close together as possible in order to receive

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identical audio signals transmitted through the plastic case 112. The electronics package 122 contains subtractive circuitry for eliminating noises propagated through the hearing aid case, as discussed above in conjunction with Figs. 1-5.

Other alternatives and variations are possible according to the present invention. For example, as illustrated in Fig. 8, the subtractive circuitry in the electronics package may include a suitable digital signal processor 723 and appropriate analog-to-digital and digital-to-analog converters 725, 727. The digital signal processor may be operative to use an audio test signal to adjust the electrical gain and phase of one microphone to minimize audio signals propagating through the hearing aid shell from appearing in the resulting electrical signal. The gain and phase of the audio signal from one microphone 720 can be varied with respect to the second microphone 730 to minimize the audio signals propagated through the hearing aid case from being present in the resulting electrical signal.

In a further embodiment of the invention, illustrated in Fig. 9, a hearing aid employs two microphones 820, 821 that form a directional microphone by processing the signals from the two microphones using a suitable signal processor 823, as known in the art. A third microphone 830 is provided, isolated from free air in an enclosure 834 as described above. The third microphone 830 is mechanically attached to the same structure as the first and second microphones 820, 821. The output of the third microphone is directed to a buffer amplifier 825 with a gain of one. The buffer

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amplifier provides two identical output signals from the microphone 830.

The outputs of the buffer amplifier are introduced to two separate difference devices, such as differential amplifiers 827, 828, at which the signals from the first and second microphones 820, 821 are subtracted from the signal from the third, sealed microphone 830. In this manner, any sound propagated through the shell of the hearing aid is subtracted from the signals from the two microphones 820, 821 exposed to free air independently before the signals from the two free air microphones enter the signal processor 823. Thus, any sound propagated through the shell is eliminated from both microphones 820, 821 before the audio signals are processed to provide directional information and to eliminate other types of "external" noise.

In an alternative, the subtraction and signal processing may be performed in a single signal processor. Thus, the signal from the third microphone may be sent directly to the signal processor, eliminating the buffer amplifier and the two differential amplifiers, although use of the buffer amplifier and two differential amplifiers is preferred.

Although the invention has been particularly described with respect to an in-the-ear type of hearing aid, the invention can also be implemented in a behind-the-ear type of hearing aid.

An embodiment is illustrated in Fig. 10 which shows a behind-the-ear type of hearing aid 900 which includes a case 902 having a first microphone 904 mounted on the case, a second microphone 906 mounted on the case within an enclosure 908 which seals microphone 906 from free air

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similarly to the embodiments described above. A third microphone 910 is mounted on the case and receives sound from a hollow tube 912 which has one end confronting microphone 910 and the other end near the outer edge of the ear 914. The tube 912 is joined to tube 918, such as by a clip 913, so that the end of tube 912 is positioned at the outer edge of the ear.

A loudspeaker 916 is on the case 902 and is coupled to one end of a hollow tube 918 such as by a coupling 917. The other end of tube 918 resides in an inner or deeper portion of the ear canal 920. The tube 918 is centered and retained within the ear canal by a spoked disk 922, shown more particularly in Fig. 11. The support disk has an outer ring 924 and spokes 923 which define open spaces between adjacent spokes to provide an open structure to permit the free flow of sound into and out of the ear and which eliminates the occlusion effect. The occlusion effect occurs when the ear is blocked or covered and as a result of which the person whose ear is blocked hears his or her own voice in an amplified manner and often with enhanced bass and echo tones.

Some portion of the sound emanating from the inner end of tube 918 exits the ear and is picked up by the end of tube 912 and propagated to microphone 910. The signals from the microphones are coupled to a signal processor 928 within the case and the gain and phase of the signals picked up by tube 912 and directed to microphone 910 are such that the sound picked up by microphone 910 will be cancelled thereby minimizing acoustical feedback which could other occur by sound emanating from the ear and detected by microphone 904. While some sound emanating from the ear may still be

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picked up by microphone 904, the majority of the sound emanating from the ear will be cancelled by the microphone 910 and associated signal processor 928.

The gain and phase of the signal from microphone 910 is initially set by generating test frequencies at the loudspeaker 916 and adjusting the gain and phase in the signal processor to cancel out the test frequencies picked up by microphone 910. The settings of gain and phase are stored in a memory of the signal processor for operational use. The gain and phase settings are determined by the testing performed in situ with the hearing aid installed on the ear of a user so that the gain and phase are corrected specifically for each person and the individual hearing aid. In the illustrated embodiment the audio signal from microphone 910 is nulled against the net signal from microphone 904 after subtraction of the signal from sealed microphone 906. In a variation of the embodiment shown in Fig. 10 the sealed microphone 906 can be eliminated. In this latter embodiment, the signal from microphone 910 is nulled against the signal from microphone 904.

The invention is not to be limited by what has been particularly shown and described, except as indicated by the appended claims.

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